RAREFACTION WAVE GUN TANK MAIN ARMAMENT DEMONSTRATOR

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ABSTRACT

RArefaction waVe guN (RAVEN) propulsion is a widely acclaimed method to impart maximum energy into a projectile while endowing the launcher with the least recoil momentum and thermal heating. It was originally conceived in 1999 to meet the ambitious lethality and strategic deployability objectives of the future combat systems (FCS) to drive off a C130 transport ready for combat. RAVEN was removed from consideration to meet FCS lethality requirements due to the immaturity of the technology. This paper presents the experimental results of a brass-board tank main armament demonstration system based upon RAVEN propulsion. This technology profoundly alters the system integration options for guns.

1 INTRODUCTION

The tank main armament demonstrator operates on the rarefaction wave gun principle. In such a gun the breech is intentionally opened while the projectile is still traveling down the barrel. This causes a dramatic drop in chamber pressure as pressure rapidly bleeds off through the open breech. Although at first it would be anticipated projectile acceleration would be compromised, such losses cannot occur until the pressure loss wave (i.e., rarefaction wave) reaches the bullet. The speed of this rarefaction wave is limited by the speed of sound within the propellant gas. The propulsion of the bullet can only be compromised after the bullet 'hears' the venting.

The implication is that if the bullet leaves the muzzle, as the rarefaction wave reaches it, the muzzle velocity will not be compromised. This concurrence of events is considered to reflect synchronized timing. Venting later will never slow the bullet. Venting earlier will progressively slow the bullet more as recoil is further reduced or eliminated. It has been shown that synchronized operation typically occurs when venting commences when the bullet has traveled between one fourth and one third of its travel down the bore.

Fig. 1. is a video snapshot of the 105mm RAVEN firing at Ares, Inc., Port Clinton, OH, on 13 August 2008. The muzzle is to the right, and the RAVEN nozzle integrated to the breech is to the left. Unlike prior art recoilless rifles, the rearward venting commenced nominally two milliseconds prior to muzzle exit of the

Fig. 1. Image of 105mm RAVEN firing.

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projectile. Directed through an engineered expansion nozzle to cool the gas and maximize developed thrust; the rearward discharge indicates reduced flash and improved directionality relative to the muzzle flash.

1.1 Rarefaction and Shock Waves

Although a positive pressure shock wave can move through a column of gas at faster than the speed of sound, a rarefaction wave cannot. In the case of a shock wave, the increased pressure of the gas behind the wave front results in adiabatic heating of the gas, increasing its sound speed. This allows a coalescence of pressure waves to form an abrupt increase in pressure at the shock front that can travel somewhat faster than the speed of a sound wave ahead of the shock.

To the contrary, a rarefaction wave reduces gas pressure and density behind the wave front. As gas density is reduced, it becomes more rarefied. This rarefaction progressively cools the gas, decreasing its sound speed and weakening the pressure loss gradient as the wave propagates.

As such waves propagate through the gas column, the local flow velocity of the column must be arithmetically added to the local sound speed to properly compute the rarefaction wave velocity. In the case of a synchronized RAVEN, the local gas velocity may initially be approximated as zero upon first opening the breech and that of the projectile's muzzle velocity upon reaching it at shot exit. Thus, an average gas velocity contribution to the rarefaction wave of half the muzzle velocity provides a reasonably accurate first estimation. A reasonable first approximation of the speed of sound within a gun is one thousand meters per second. Dividing the length of the gun by the sum of sonic and average gas velocity estimates the extent to which RAVEN venting may precede shot exit without any loss in muzzle velocity.

Accurate simulation of rarefaction wave propagation has been undertaken using a lumped parameter interior ballistic code and two separate one dimensional interior ballistic codes. The closed breech code NOVA (Gough, 1990) was employed (Kathe, 2001) to determine rarefaction wave propagation rates through several gun systems without computing effects behind the wave front. A lumped parameter code incorporating blow-back recoil was developed to predict wave front propagation rates in support the design of RAVEN technology demonstrators (Kathe, 2002). A new one-dimensional code named Rarefaction Wave Recoil (RAR) was specifically developed to model RAVEN (Coffee, 2006). It explicitly simulates the rarefaction wave process to include estimation of thrust produced and reduction of thermal heating of the bore.

2 PRIOR DEMONSTRATORS

2.1 35mm RAVEN

The 105mm RAVEN was preceded by a 35mm blow back bolt operated RAVEN. Unlike a traditional breech ring and block which provides containment of chamber pressure by stresses developed within interlocking steel threads or lugs, a blow back configuration provides inertial containment. It is not structurally fixed to the cannon, rather, it is allowed to be displaced rearward much as the bullet is allowed to travel forward towards the muzzle. As typified by the M3A1 45 caliber submachine gun (a.k.a., grease gun) blow back requires a far more massive bolt than bullet. This ensures that the resulting stretch of the cartridge case is sufficiently small to prevent rupture and maintain reliable obturation (pressure seal) of chamber (Chinn, 1955).

The blow-back approach was modified for the 35mm RAVEN demonstration to intentionally rupture the cartridge case head from the body. It was then allowed to recoil within a chamber extension a fixed distance prior to 'uncorking.' A nylon obturator was introduced to the head to maintain a sliding pressure seal in analogy to the rotating band fixed to the bullet. Variation in vent timing was provided by using two different weight bolts, nominally 21Kg and 36Kg and four different length vent extensions. Total recoil stroke to vent was varied from nominally 40mm to 90mm.

Using this approach, recoil momentum was cut by half and barrel heating was reduced by 40%. Interestingly, the reverse blow down of the RAVEN was observed to pneumatically eject the ruptured cartridge case body from the chamber (Kathe, 2002).

A disadvantage to the 35mm demonstrator was the larger diameter of the 55mm bolt versus the 35mm projectile. The resulting momentum imbalance within the chamber applied substantial blow-forward acceleration to the barrel.

A second disadvantage to the demonstrator was the use of disposable crush rods to arrest recoil.

A third disadvantage of the demonstrator was the relatively low muzzle velocity of the bullet. As muzzle velocity is increased, so are this ratio and the ratio of latent impulse of the propellant gas to projectile momentum. Thus, the recoil abating thrust developed by a synchronized RAVEN may begin to encroach upon recoilless operation when firing kinetic energy rounds.

2.2 MRAAS

Following the successful trials in 35mm, the successful large caliber RAVEN was engineered using design and hardware assets remaining from the 105mm Multi-Role Armament and Ammunition System (MRAAS) program. MRAAS incorporated a novel swing chamber and cased telescoped ammunition that provided 120mm tank gun lethality from an armament system that lent it self to compact combat system integration.

Modifications to the gun and ammunition design to achieve RAVEN propulsion were minimized to control costs, accelerate schedule, and minimize risk.

3 105MM RAVEN HARDWARE

As shown in Fig. 2., the 105mm RAVEN borrowed the MRAAS swing chamber ammunition interface. This provides a straight forward and simple means to load ammunition. The nozzle is integrated to the left and shot travel is to the right.

Incorporated within the breech end is a fixed annular vent and expansion nozzle within which a 105mm blow back bolt is positioned. Centered within the aft end of the cartridge case is a 105mm consumable disk. Upon ignition of the cartridge, the consumable disk is pressed into the forward face of the blow back bolt and the vent mechanics proceed with great similarity to the 35mm demonstrator. However, since the bolt and projectile have the same diameter, the 105mm RAVEN imparts neither forward momentum nor rearward recoil to the launch tube. This eliminates a primary load that contributes to the gun dynamics that beget dispersion.

A second advance embodied within the 105mm demonstrator is the application of variable orifice hydraulic recoil brakes and recuperators. These arrest the rearward recoil motion of the bolt and return it to its battery position. The bolt is coupled to the recoil cylinders through the outer expansion nozzle housing. Four vanes cast into the nozzle, as seen in Fig. 3, merge to support the coaxial bolt. This allows a convenient integration method for the recoil cylinders and allows a portion of the thrust generated to directly arrest the recoil motion.

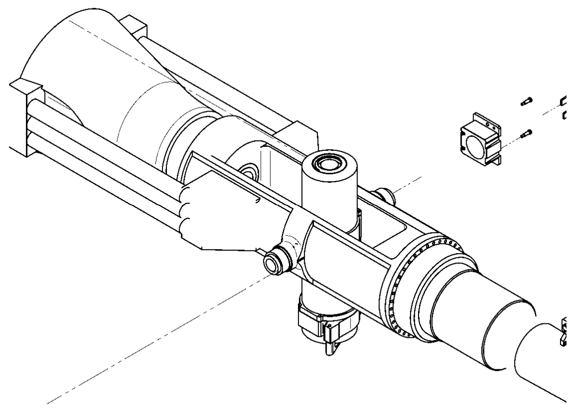

Fig. 2. 105mm RAVEN swing chamber.

Fig. 3. RAVEN assembly team.

The coaxial configuration of inner and outer expansion nozzles may be appreciated by the line drawing of Fig. 4, which shows a centerline cross section of the bolt, nozzles, chamber, and gun tube with the bolt fully forward in its battery position.

Vent timing may be altered by the use of different bolt faces. Blunt faced bolts require a greater recoil distance to vent. Progressively more conical bolts vent earlier. This is shown in Fig. 5. where the two distances listed indicate first the distance to initiation of the venting and second the approximate distance to fully open the vent. Between these two positions, choked flow is anticipated within the annular gap between the bolt face and nozzle.

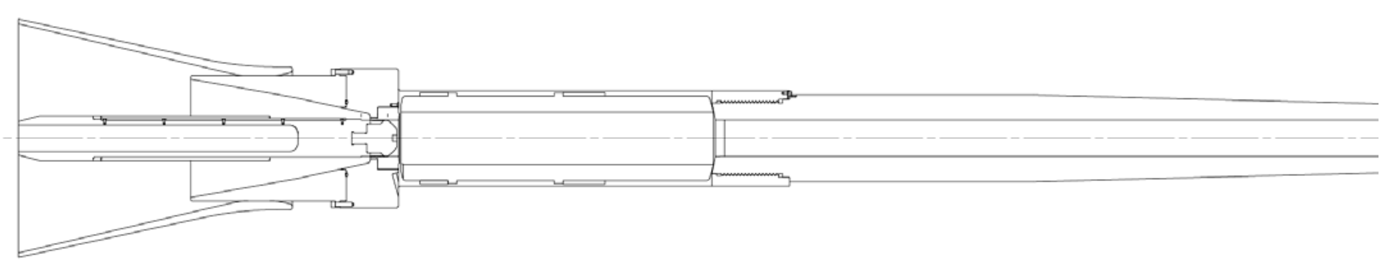

Fig. 4. 105mm RAVEN line drawing .

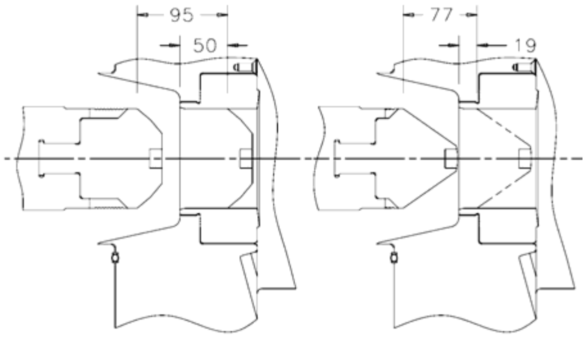

Fig. 5. Millimeters of displacements to initiate and fully open the vent for a blunt and conical bolt face.

4 TEST RESULTS

Six shots were successfully fired from February to August of 2008 with no major component failure or unexpected dynamic response. The table includes predicted results using RAR (personal communication, R. Berggren of Benét) and experimental findings.

Muzzle velocity was measured using standard screens and compares well with predictions. Chamber pressure was recorded using a novel integrated transducer and recorder unit inserted into the chamber. The experimental readings are consistently lower than predicted. As the muzzle velocities compare favorably and the experimental trends are consistent, the calibration is suspect. Experimental momentum was inferred by recording the velocity of components during recoil. Its fidelity is subject to frictional affects, but compares reasonably well with predicted values.

For a point of reference, the predicted results for a close-breech configuration, scheduled as shot 17 are presented supporting recoil reduction by a factor of two.

CONCLUSIONS

A truly large caliber rarefaction wave gun has been designed, fabricated, and is currently undergoing test and validation..

Measured muzzle velocities support the fundamental precept of RAVEN that venting a large caliber gun during the ballistic cycle does not slow the bullet.

RAVEN has been successfully integrated with an unusual swing-chamber munitions handling interface. This interface allows straightforward combat system integration of this armament technology.

REFFERENCES

Chinn, G. M., 1955, The Machine Gun, Volume IV, Department of the Navy, 638.

Coffee, T. P., 2006, Modeling the 35mm Rarefaction Wave Gun, JANNAF 2006-0166J, 10.

Gough, P. S., The XNOVAKTC Code, Portsmouth, NH, 1990.

Kathe, E., Dillon, R., Sopok, S., Witherell, M., Dunn, S., and Coats, D., 2001 Rarefaction Wave Gun Propulsion, *JANNAF 50th Propulsion Meeting*, Salt Lake City, UT, 14.

Kathe, E., 2002, Rarefaction Wave Gun Propulsion, Doctoral Thesis, Rensselaer Polytechnic Institute, Troy, NY, 298.

Table 1. Predicted and Experimental Results.

Shot number			1	2	3	4	5	6	17
Date			2/19/08	4/14/08	5/1/08	5/19/08	8/13/08	8/27/08	TBD
Parametric Configuration	Distance to Vent	mm	50	42.2	42.2	50	43	37	Closed
	Projectile Mass	Kg	8.31	8.31	8.31	8.31	8.31	8.31	8.31
	Charge Mass	Kg	4.97	5.65	6.29	6.78	6.75	7.05	6.98
	Chamber Volume	L	7.71	7.71	7.71	7.71	7.78	7.84	-
Predicted Results	Muzzle Velocity	m/s	1,118	1,261	1,396	1,501	1,491	1,552	1,573
	Max Pressure	MPa	217	306	454	563	551	643	669
	Momentum	Ns	9,578	10,650	12,602	14,672	14,005	14,443	24,246
Experimental Results	Muzzle Velocity	m/s	-	-	1,156	1,344	1,374	1,383	-
	Max Pressure	MPa	167	225	-	389	-	447	-
	Momentum	Ns	-	-	12,362	12,878	12,726	-	-